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Contributed paper

The auto-correlator for the soft X-ray FEL FLASH at DESY

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A new auto-correlator has been developed, built and implemented. It contains eight mirrors on an optical bench, which are independent, adjustable in the nrad and nm range. A parallelogram-based delay stage moves two of the mirrors over ±15 mm with 30 nm resolution and without random parasitic motions. The paper presents the new ideas applied in the design of this device.

1. Introduction

For time resolved experiments at BESSY and especially at the VUV-FEL FLASH, an auto-correlator (AC) has been designed and built. It contains a beam splitter and a variable delay line for one of the partial beams. The beam is typically merged at the focus. For this purpose, eight mirrors are mounted on an optical bench where two mirrors are at the parallelogram-based delay stage. The other six mirrors are on new flexure mirror support which guides the three Cartesian rotations around the reflecting point of the mirror surface. The complete device is in an ultrahigh vacuum (UHV) chamber and is tubular with a length of 1800 mm and a diameter of 500 mm.

2. Optical principle

The first mirror in the AC is the beam splitting mirror (M1). It divides one geometrical half of the beam and deflects it from the middle axis of the beam (figure 1) (Mitzner *et al.* 2008).

The second part of the beam is reflected by a second mirror (M2) out of the beam axis. Both partial beams are parallelly offset by the mirrors M3 and M5. The mirrors M3 and M4 in the lower partial beam are rigidly connected to each other and are movable up and down to change the length of the beam path. A high precision linear stage based on a flexure parallelogram is used to translate the mirrors. The mirrors M7 and M8 are merging the half beams in the conjoint focus. At one position in the stroke both lengths of beam path are equal where the partial beams interfere. The precision of the translation allows interference experiments, the measurement

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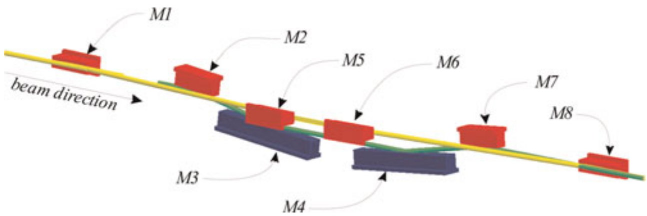

FIGURE 1. Beam layout of the AC.

of the length of femtosecond-pulses and pump/probe experiments (Mitzner *et al.* 2005, 2009).

3. Adjustable frame

The AC's UHV chamber is supported by an active frame that allows the alignment of the AC's and FEL's optical axes (figure 2). For this purpose, the legs of the frame are adjustable in length. They are arranged at an angle of 45° to the ground and their centrelines intersect with the optical axis of the AC. At both ends, the legs are equipped with flexure ball joints for connecting to the ground plate and the chamber wall. The joints are short pieces of a steel rope of a diameter of 55 mm (Noll 2002). The movement of the struts translates and rotates the AC in and around the X and Y axes.

There are four square tubes welded onto the lower side of the chamber in order to define the translation along the Z-axis and the rotation around the Z-axis.

4. Optical bench

The optical bench of the AC is modelled as a large thin-walled tube with an octagonal cross section (figure 3). It consists of an upper and a lower half shell that are screwed together. This design provides a closed tubular supporting structure with high stiffness and less space. Elliptic and circular cuts in the wall of the

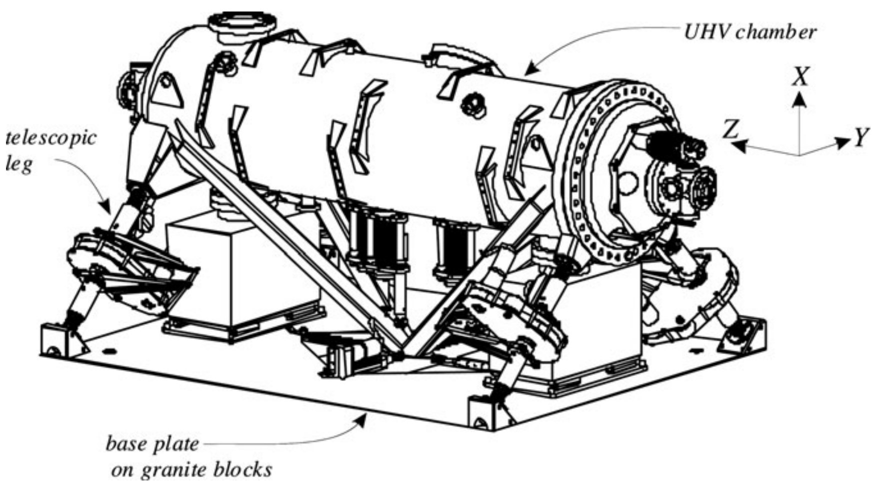

FIGURE 2. The AC mounted on a baseplate.

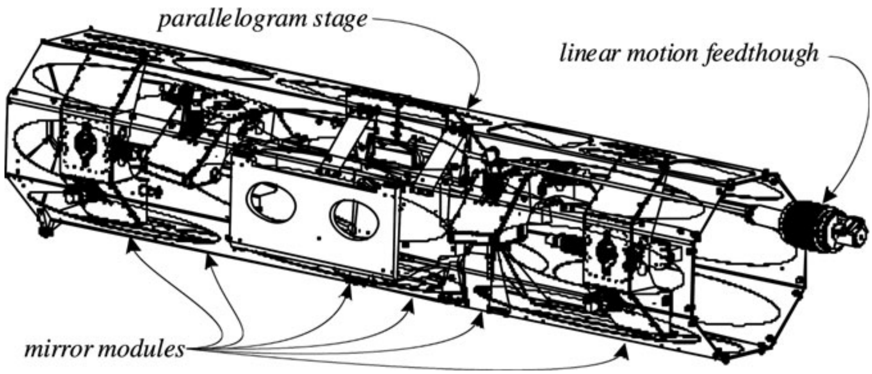

FIGURE 3. Optical bench with six adjustable mirror modules and a parallelogram stage with two mirrors.

optical bench provide the access to the mirrors and all the components possible. One end of the optical bench is fixed to the main plate of the chamber. The other end is supported by two rollers that are running on the lower wall of the chamber. Thus, if the main flange is removed the optical bench can be extracted with everything that comes with it and modified at will.

5. Mirror units

The angles of the mirrors M1, M2, M5, M6, M7 and M8 are adjustable in order to align the beam paths. A generic mirror module was developed, which fulfils the requirements of all six mirrors (figure 4). They are mounted like an inner cross bridge in the octagonal optical bench. The mirrors are mounted on top of a flexure

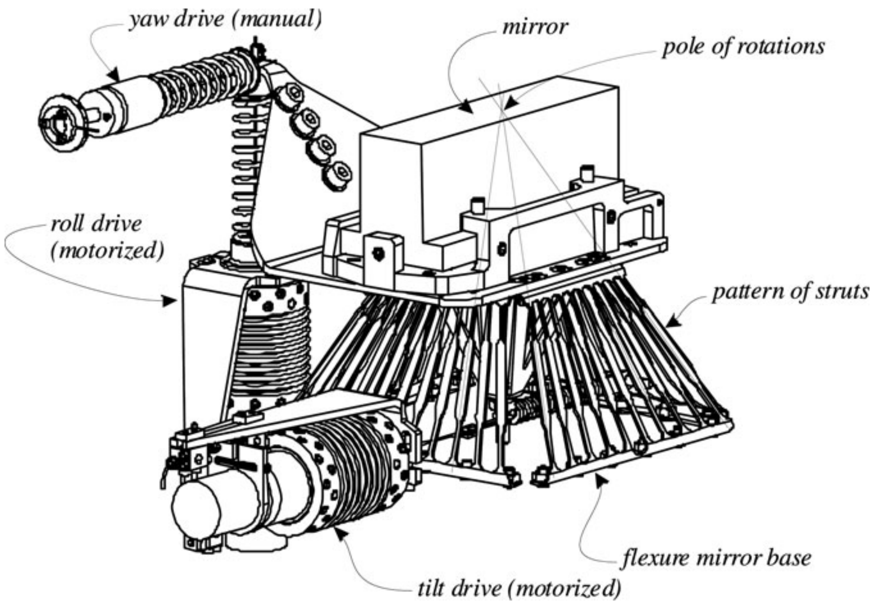

FIGURE 4. The mirror module.

structure that works like a ball joint (Noll & Lammert 2005*a*, *b*). The pole of the rotations of the ball joint is on the mirror surface at that point, where the incoming beam's middle axis hits the mirror surface. Three pre-stressed cable pullers (Noll & Lammert 2005*a*, *b*) are attached to levers driving the three Cartesian rotations of the mirror. The resolution averages 100 nrad if stepper motors with gear drives are used. For manual driven cable winches, the accuracy is some orders of magnitude lower. The range of alignment for each axis is about 10 mrad. The performance of this parallel kinematic mirror support was not characterized independent from the AC. The mentioned numbers are valid for the whole AC.

6. Delay stage

The mirrors on the delay stage (M3 and M4) are manually adjustable in its casing during the assembly and set up. The linear stage is based on a parallelogram.

The parallelogram's plates are made of high strength aluminium with incorporated flexure bending joints. The movement is driven by a high precision linear motion feedthrough with a stepper motor. A push-pull rod connects the feedthrough with a cable that is connected to the platform of the parallelogram. The connection of the push-pull rod to the feedthrough is made by a flexure ball joint based on a stainless steel rope (Noll 2002). The stroke of the parallelogram stage is ±15 mm with a resolution of 30 nm (figure 5). The parasitic cross translation is 1 mm. A parasitic rotation of some tens of μrad remains after the alignment. But it is highly reproducible over the main part of the stroke and becomes compensated by piezo actuators at the delay stage. Random parasitic motions are not detectable.

7. Conclusion

The AC has been successful integrated in beamline BL2 at the soft X-ray FEL FLASH at DESY in Hamburg. It is used to measure the average temporal coherence

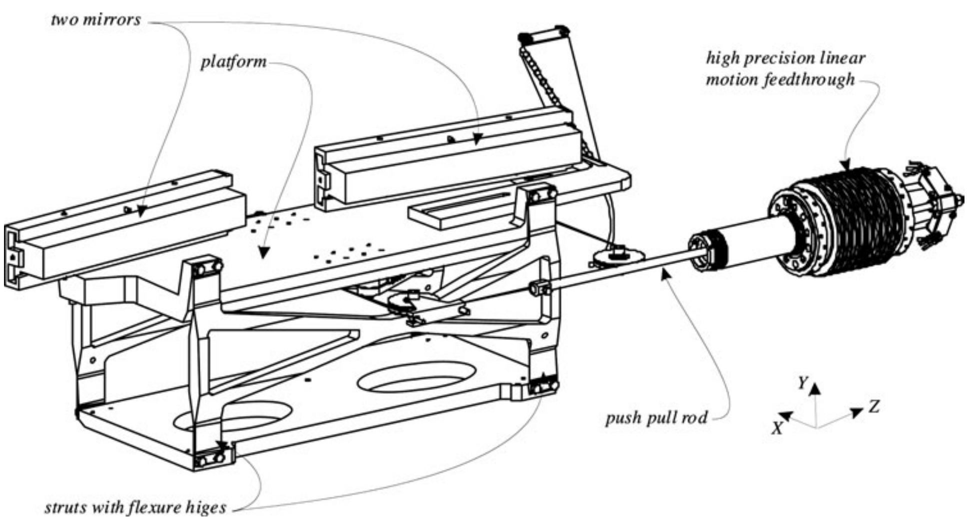

FIGURE 5. The parallelogram stage with a stroke of ±15 mm.

and the duration of the FEL pulses. It is furthermore an important precondition for many new experiments (Pfau *et al.* 2010; Günther *et al.* 2011).

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